

Study of Miniaturized Tri-band Combined-element Frequency Selective Surface (CEFSS)

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Abstract — Miniaturized combined-element frequency selective surfaces (CEFSSs) for tri-band applications are proposed using complementary structures. The three passbands of the proposed structures can be designed independently, which makes the design process much easier and more flexible than traditional tri-band FSSs. Besides, comparing to former designed combined-element FSSs, the structures proposed in this paper have smaller sizes due to the use of meandered structures, which contributes to its independence of both angle and polarization. Equivalent circuit method (ECM) is used to analyze transmission characteristics. The results between simulation and measurement agree well.

Index Terms — frequency selective surfaces, spatial filters, equivalent circuits.

I. INTRODUCTION

As a kind of spatial filters, frequency selective surfaces (FSSs) are able to transmit desired signals while reflecting unnecessary signals. The FSSs are often widely used in many fields like subreflectors, radomes and so on [1].

Multiband characteristics, which mean transmitting in several desired frequency bands, are often required in many practical applications of FSSs. Many methods have been adopted to realize multiband characteristics of FSSs. References [2-3] proposed multiband FSSs that are fulfilled by placing two different loops in one period or using a fractal loop slot. Besides, complementary structures with two transmission poles and one transmission zero were proposed in Reference [4].

Meanwhile, the sizes of FSSs are required to be small enough because of the limited areas and the need to delay grating lobes. A miniaturization design was proposed by using bending metal strips [5]. Lumped components were used to design miniaturized FSSs [6]. In Reference [7], complementary meander lines were adopted to realize a miniaturized dual-band FSS.

In this paper, two miniaturized tri-band FSSs are proposed using complementary structures. The transmission passbands and stopbands can be adjusted independently, which makes the design of these combined structures easier and more flexible. The equivalent circuit method is used to predict and analyze the characteristics of the combined-element FSS. To prove the validity, prototypes of the proposed structures are fabricated and tested with good results.

II. DESIGN AND ANALYSIS OF THE PROPOSED STRUCTURES

A. Design of The First Combined-element FSS

The single square aperture FSS has a passband with a transmission pole while the complementary meandered structures have a dual-band bandpass property with two transmission poles. The focus here is on designing tri-band FSS by combining these two structures. The combined structure is shown in Fig. 1, of which the top consists of a meandered loop and the bottom layer is composed of a meandered aperture and a single square aperture. The detailed physical parameters are listed in Table I ($\epsilon_r=2.56$).

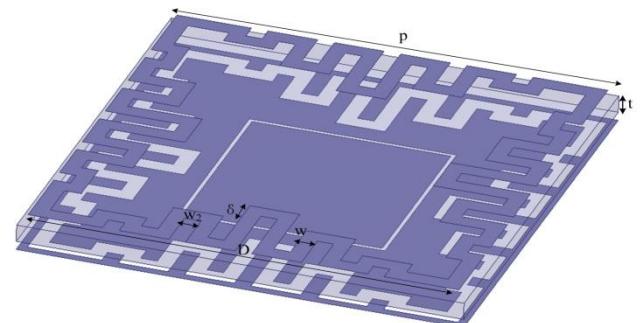


Fig. 1. Combined structure of the complementary meandered structures and the single square aperture structure

TABLE I
GEOMETRY SIZE OF THE STRUCTURE (UNIT: MM)

Parameter	<i>l</i>	<i>s</i>	<i>D</i>	<i>g</i>	<i>w</i>	<i>w₂</i>	δ	<i>t</i>
Value	5.7	0.2	10.8	0.4	0.4	0.4	0.7	0.8

As shown in Fig. 2, the combined-element FSS has three transmission poles at 2.9, 4.3 and 9.7 GHz and two transmission zeros at 3.6 and 7.6 GHz.

The electric field distributions of both front and back sides' metal surfaces are plotted in Fig. 3. From Fig. 3(a) and (b) we can find that the transmission poles at 2.9 and 4.3 GHz are introduced by the complementary meandered structures, while Fig. 3(c) demonstrates that the transmission pole at 9.7 GHz is introduced by the single square aperture. Particularly, the additional transmission zero at 7.6 GHz is introduced by the

coupling of the two structures after combination, which improves the frequency selectivity of the combined structure.

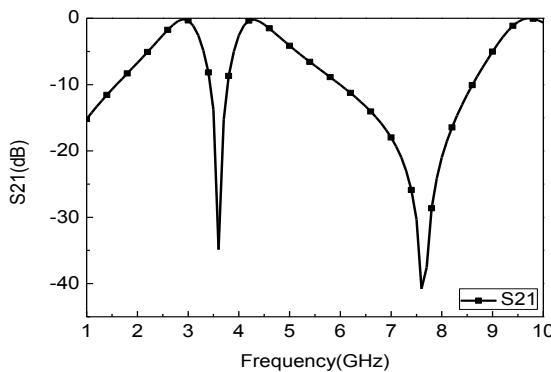


Fig. 2. Transmission curve of the complementary meandered structures and the single square aperture structure

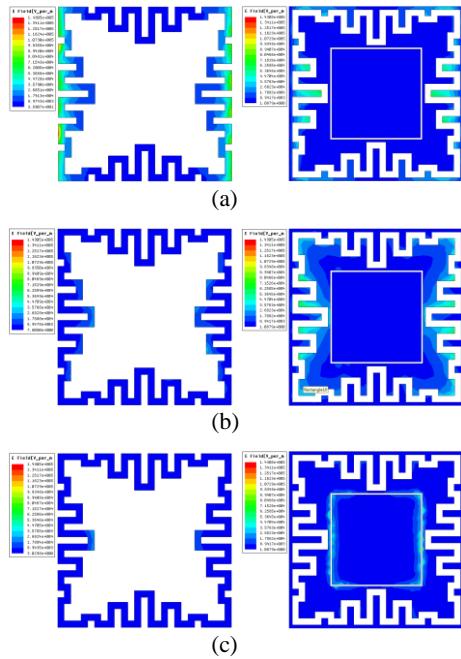


Fig. 3. Electric field distributions under different resonant frequencies, (a) $f=2.9$ GHz, (b) $f=4.3$ GHz, (c) $f=9.7$ GHz

B. Design of The Second Combined-element FSS

However, the size of single square aperture is restricted to the meandered aperture. Therefore, the corresponding transmission pole introduced by the single square aperture can't move to a lower frequency band independently.

In order to control the extra transmission pole in a lower frequency band independently, a novel miniaturized structure is proposed.

This combined structure, of which the top consists of the wire grid and the meandered loop and the bottom layer is composed of the wire aperture and the meandered aperture, is shown in Fig. 4. The detailed geometry parameters are listed in Table II ($\epsilon_r=2.56$).

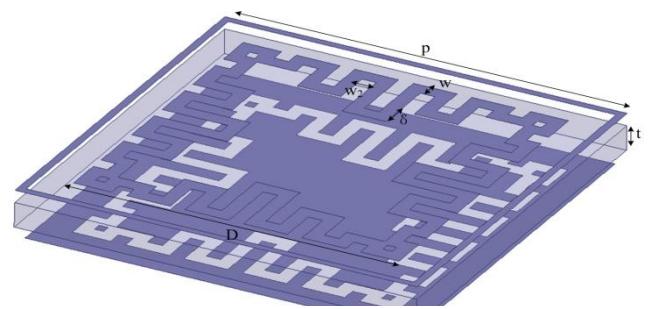


Fig. 4. Combined structure of the complementary meandered structures and the stacked wire grid and aperture grid structure

TABLE II
GEOMETRY SIZE OF THE STRUCTURE (UNIT: MM)

Parameter	p	g_1	D	g	w	w_2	δ	t
Value	11	0.4	9.3	0.4	0.4	0.4	0.7	0.8

From the transmission curve of this combined-element FSS shown in Fig. 5, we can find three transmission poles at 3.3, 4.5 and 5.4 GHz and two transmission zeros at 4.0 and 4.9 GHz, respectively.

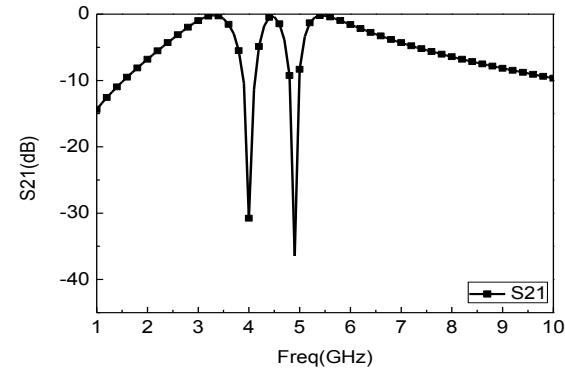


Fig. 5. Transmission response of the complementary meandered structures and stacked wire grid and aperture grid

As shown in the equivalent circuit in Fig. 6, the meandered loop and its complementary structure can be equivalent to a series resonant circuit (L_1, C_1) and a parallel resonant circuit (L_2, C_2), respectively. Meanwhile, the wire grid structure can be equivalent to the inductance L_s parallel to the series LC resonant circuit while the aperture grid structure can be equivalent to the capacitance C_s in series with the parallel LC resonant circuit. The free space at both sides of the combined-element FSS is modeled as transmission lines with a characteristic impedance of $Z_0=377$ Ω . The dielectric substrate supporting this structure can be considered as a short transmission line with a length of t and its wave impedance is $Z_t=Z_0/\sqrt{\epsilon_r}$.

The first transmission pole is determined by the equivalent inductance L_s and the equivalent capacitance C_s . At this point, the series resonant circuit (L_1, C_1) and the parallel resonant circuit (L_2, C_2) can be viewed as being open and short,

respectively. Another two transmission poles and the second transmission zero are mainly determined by the series LC resonant circuit and the parallel LC resonant circuit. Particularly, the first transmission zero is introduced by the couplings of two complementary structures after combination.

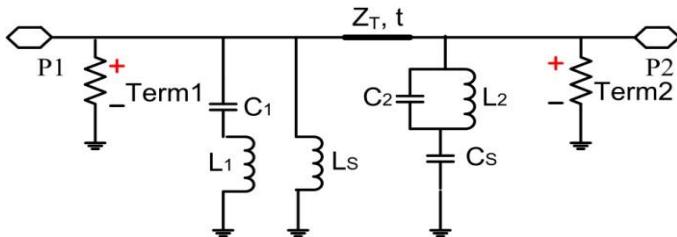


Fig. 6. Equivalent circuit of the combined-element structure

From the analysis above, these two combined-element FSSs both provide three transmission poles and two transmission zeros, which improve the frequency selective characteristics and can be applied in many fields of multiband systems. The sizes of the combined-element FSS are reduced to about $\lambda_{pass1}/10$ due to the introduction of miniaturized structure, which ensures better angular stability and polarization stability than traditional FSSs.

III. EXPERIMENTAL VERIFICATION

Prototypes of the combined-element FSSs are fabricated and measured in order to demonstrate the validity of the proposed designs.

Transmission responses of each structure under incidence angles of 0° and 15° for both TE and TM polarizations are compared in Fig. 7 and Fig. 8, respectively. Only a little deviation can be observed, and the shift of the measured operating frequency can be attributed to the inaccuracy of fabrication. In general, the measured result agrees well with the simulation.

IV. CONCLUSION

Two miniaturized FSSs with tri-bands properties are proposed based on combined-elements. The combined-element FSSs have smaller size than traditional tri-band FSSs due to the use of meandered structures, which contributes to its independence of both angle and polarization. Equivalent circuit method is carried out to design and analyze. Prototypes of the structures are fabricated for demonstration, and the measurement results agree well with the simulation results.

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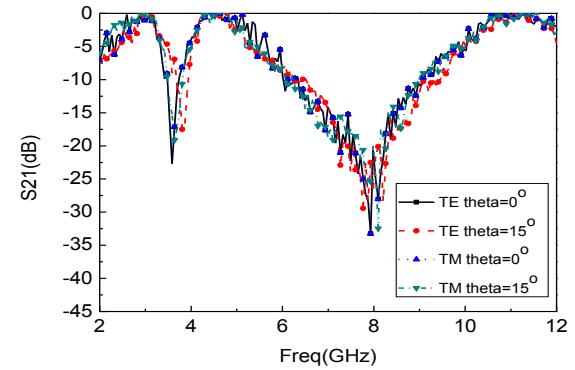


Fig. 7. Transmission responses of the first combined-element FSS

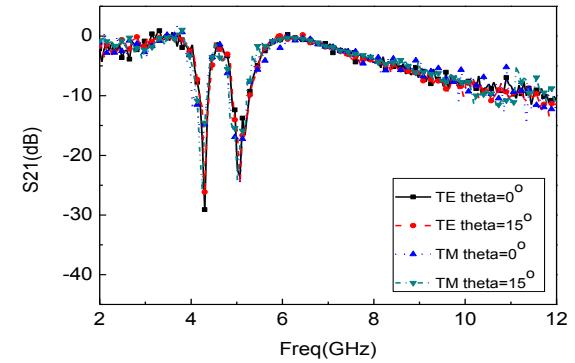


Fig. 8. Transmission responses of the second combined-element FSS

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